Example 4a: MAC/GMC Internal Loading Options

This example problem demonstrates all of the internal MAC/GMC 4.0 mechanical loading options that are applicable to repeating unit cell analysis. These internal loading options allow for the easy application of many common uniaxial and biaxial loading conditions. In the present example, doubly periodic GMC is employed in conjunction with loading options 1 through 10. For triply periodic GMC, loading options 1 – 8 are identical to the coinciding doubly periodic GMC loading options. However, loading options 9 and 10 are different, and triply periodic GMC allows two additional loading options, 11 and 12. For more information on the code's internal mechanical loading options, see the MAC/GMC 4.0 Keywords Manual Section 4.

MAC/GMC Input File: **example_4a.mac**

```
MAC/GMC 4.0 Example 4a - RUC analysis internal loading options
*CONSTITUENTS
  NMATS=2
  M=1 CMOD=6 MATID=E
  M=2 CMOD=4 MATID=A
*RUC
  MOD=2 ARCHID=13 VF=0.25 R=1.25 F=1 M=2
*MECH
  LOP=1
#  LOP=2
#  LOP=3
#  LOP=4
#  LOP=5
#  LOP=6
#  LOP=7
#  LOP=8
#  LOP=9
#  LOP=10
# -- Note: LOP > 6 are biaxial & require 2 load profiles
  NPT=2 TI=0.,200. MAG=0.,0.02 MODE=1
#  NPT=2 TI=0.,200. MAG=0.,0.02 MODE=1
*THERM
  NPT=2 TI=0.,200. TEMP=650.,650.
*SOLVER
  METHOD=1 NPT=2 TI=0.,200. STP=1.
*PRINT
  NPL=6
*XYPLOT
  FREQ=5
  MACRO=6
   NAME=example_4a X=1 Y=7
   NAME=example_4a X=2 Y=8
   NAME=example_4a X=3 Y=9
   NAME=example_4a X=4 Y=10
   NAME=example_4a X=5 Y=11
   NAME=example_4a X=6 Y=12
  MICRO=0
*END
```

Annotated Input Data

1) Flags: None

2) Constituent materials (***CONSTITUENTS**) [KM_2]:

Number of materials:	2	(NMATS=2)
Materials:	SiC fiber	(MATID=E)
	Ti-21S	(MATID=A)
Constitutive models:	SiC fiber: linearly elastic	(CMOD=6)
	Ti-21S matrix: Isotropic GVIPS	(CMOD=4)

3) Analysis type (***RUC**) → Repeating Unit Cell Analysis [KM_3]:

Analysis model:	Doubly periodic GMC	(MOD=2)
RUC architecture:	26×26 circular fiber, rect. pack	(ARCHID=13)
Fiber volume fraction:	0.25	(VF=0.25)
RUC aspect ratio:	1.25	(R=1.25)
Material assignment:	SiC fiber	(F=1)
	Ti-21S matrix	(M=2)

4) Loading:

a) Mechanical (***MECH**) [KM_4]:

Loading option:	11-component	(LOP=1)
	22-component	(LOP=2)
	33-component	(LOP=3)
	23-component	(LOP=4)
	13-component	(LOP=5)
	12-component	(LOP=6)
	11- & 22-components	(LOP=7)
	22- & 33-components	(LOP=8)
	11- & 23-components	(LOP=9)
	22- & 13-components	(LOP=10)
Number of points:	2	(NPT=2)
Time points:	0., 200. sec.	(TI=0.,200.)
Load magnitude:	0., 0.02	(MAG=0.,0.02)
Loading mode:	strain control	(MODE=1)

In order to execute the code using each of the ten loading options, the appropriate lines in the input file must be commented and uncommented. For loading options 7 – 10, two load components are applied to the composite simultaneously. Thus, two sets of data are necessary to specify time-magnitude points and the loading mode (i.e., one set for each component). These sets of data are input on two separate lines in the MAC/GMC 4.0 input file. The identical loading history is applied for all loading options in this example. Note that loading options 4 – 6, 9, and 10 involve application of shear strains. MAC/GMC 4.0 employs engineering shear strains (often denoted by γ) as opposed to tensorial shear strains (often denoted by ε). See Section 4 of the Keywords Manual for additional information on the mechanical loading options.

b) Thermal (***THERM**) [KM_4]:

Number of points:	2	(NPT=2)
Time points:	0., 200. sec.	(TI=0.,200.)
Temperature points:	650., 650. °C	(TEMP=650.,650.)

c) Time integration (***SOLVER**) [KM_4]:

Time integration method:	Forward Euler	(METHOD=1)
Number of points:	2	(NPT=2)
Time points:	0., 200. sec.	(TI=0.,200.)
Time step sizes:	1. sec.	(STP=1.)

5) Damage and Failure: None

6) Output:

a) Output file print level (***PRINT**) [KM_6]:

Print level:	6	(NPL=6)

b) x-y plots (***XYPLOT**) [KM_6]:

Frequency:	5	(FREQ=5)
Number of macro plots:	6	(MACRO=6)
Macro plot names:	example_4a	(NAME=example_4a)
Macro plot x-y quantities:	ε_{11}, σ_{11}	(X=1 Y=7)
	ε_{22}, σ_{22}	(X=2 Y=8)
	ε_{33}, σ_{33}	(X=3 Y=9)
	γ_{23}, σ_{23}	(X=4 Y=10)
	γ_{13}, σ_{13}	(X=5 Y=11)
	γ_{12}, σ_{12}	(X=6 Y=12)
Number of micro plots:	0	(MICRO=0)

7) End of file keyword: (***END**)

Results

Figure 4.1 shows that, among the plots associated with a single applied load component, the normal response of the repeating unit cell in the fiber direction is stiffest, followed by the normal response in the two transverse directions, with the three shear response curves exhibiting significantly more compliance. Figure 4.2 shows the composite response when two strain components are applied simultaneously. Most interesting are the LOP=8 results, which indicate that the composite response is significantly stiffer when $\bar{\varepsilon}_{22}$ and $\bar{\varepsilon}_{33}$ are applied simultaneously compared to when each component is applied individually (see LOP=2 and LOP=3 results in Figure 4.1). This is caused by the constraining effect of the biaxial loading in addition to the higher hydrostatic stress state induced when applying the components simultaneously (which tends to suppress the inelastic deformation in the matrix).

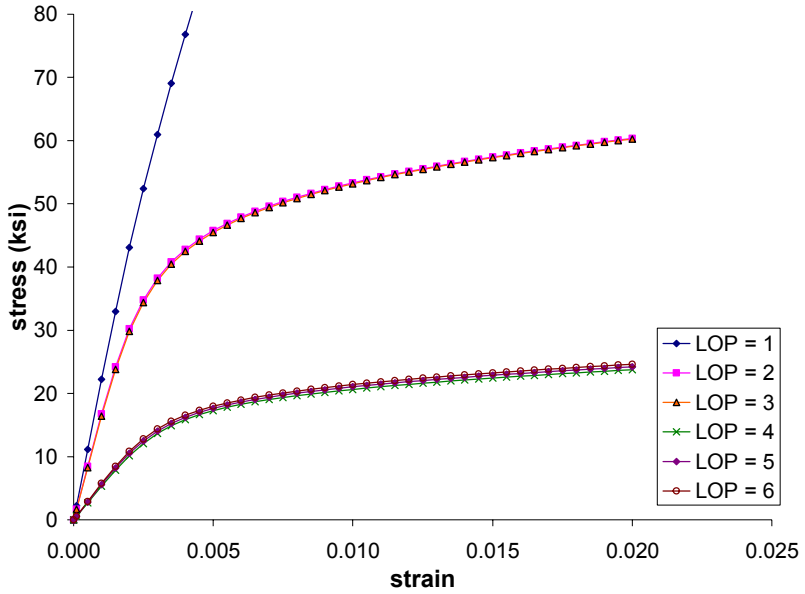

Figure 4.1 Example 4a: plot of the simulated stress-strain response for a 0.25 fiber volume fraction SiC/Ti-21S composite at 650 °C where MAC/GMC 4.0 mechanical loading options 1 – 6 have been employed.

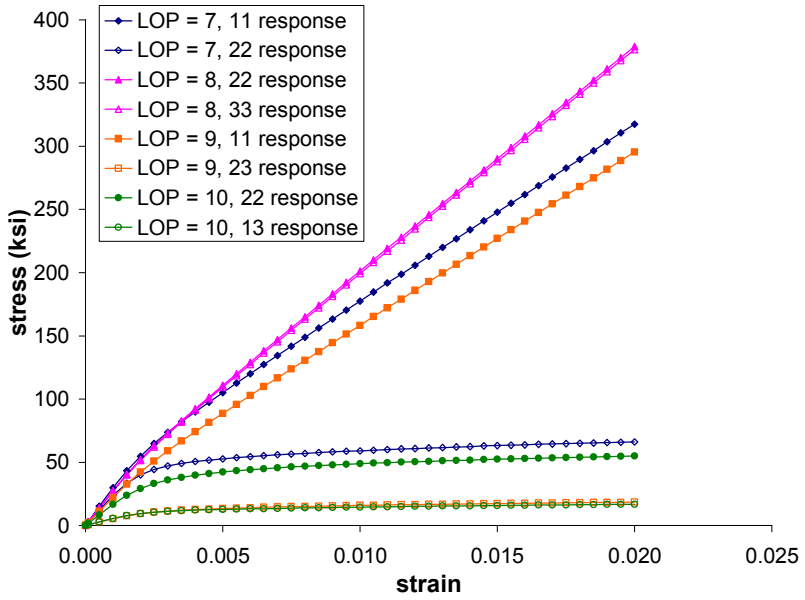

Figure 4.2 Example 4a: plot of the simulated stress-strain response for a 0.25 fiber volume fraction SiC/Ti-21S composite at 650 °C where MAC/GMC 4.0 mechanical loading options 7 – 10 have been employed.